Market Analysis of Israeli CSP Technologies in the Chinese Market

by

Meiling Shi

Dr. Lincoln Pratson, Adviser

04/16/15

Masters project submitted in partial fulfillment of the requirements
for the Master of Environmental Management degree
in the Nicholas School of the Environment

Duke University

2015

ABSTRACT

Israel is one of the leading countries in CSP technology development. A few startups have been working to bring different CSP technologies into the power generation market. However these companies have encountered various barriers in deploying CSP projects in their homeland despite the abundant sunlight and know-how Israel has. Acquiring land permit could take years while time is what a capital-intensive technology startup cannot afford. Monopoly in the power market and lack of incentives has taken a toll on the renewables sector in Israel.

Meanwhile, China has been progressing to establish its own CSP power market. Supporting policies are on their way while a few projects are already under construction. CSP power plants with storage capacity can produce utility-quality electricity, which has much less disturbance to the grid compared to PVs and wind energy. Yet the development of CSP technologies in China is limited. Introducing Israeli CSP technologies into the Chinese market could be one of the solutions that can benefit both sides.

The market analysis focuses on three companies: HelioFocus, AORA-Solar and BrightSource. Based on the study of their technologies and the particular case of the Chinese CSP market, models are developed to explore their market potentials. HelioFocus could foresee an encouraging share in the CSP market through replacing part of the installed capacity from the existing coal-fired power plants. Its thermal boosting system is ideal in high-DNI provinces such as Inner Mongolia, Gansu and Qinghai. AORA-Solar's hybrid system focuses on off-grid community-based power generation. However, industrial implementation would be a more viable approach. BrightSource has the portfolio both the Chinese government and local investors desire; in that they build large-scale systems and they already have power plants operational. All of these will help accelerate their development in China.

TABLE OF CONTENTS

TABLE OF FIGURES

AKNOWLEDGEMENTS

I would like to thank Dr. Lincoln Pratson, my advisor, for all of his guidance and support during all of the phases of this Master's Project.

INTRODUCTION

Compared to the rapid growth of solar PVs and wind energy, Concentrated Solar Power (CSP) seems to be the unlucky child. Both generating electricity through utilizing the energy from the sun, CSP technologies experienced an early start, yet considerably lagged behind solar PVs. The plunging PV prices keep squeezing the market space of CSP technologies. The once prominent CSP pioneer, SOLEL – acquired by Siemens at $ 418 million in 2009, was abandoned after China flooded the market with much cheaper PVs (Wesoff 2013). Currently CSP has not yet reached the economy of scale and technological maturity. The initial investment for a CSP power plant is often large – the current largest CSP project in the world cost $2.2 billion to build (BrightSource 2014). The performance of CSP power plants also encountered skepticism. The favorable policies in supporting CSP development are lacking as well. All of these factors deter the investors and project developers.

However, perhaps one should not compare one form of technology to another, given they all behave differently, possess different merits and serve different needs. CSP technologies are capable of storing energy more economically, which makes CSP ideal for grid connectivity to serve base load. Recently CSP has received a lot of attention. A few countries and companies are making huge effort to promote CSP technologies and construct CSP power plants worldwide; among which, Israel is one of the leading countries in developing CSP technologies. However, despite the abundant sunlight and the booming high-tech industry in Israel, CSP technologies did not experience fast growth, largely due to its small market size and lack of incentive policies. Meanwhile, solar thermal markets are growing elsewhere, notably Spain and U.S. Most of the current CSP power plants are concentrated in these two countries. Emerging markets including China, India, Chile, Middle East and South Africa have huge potentials with their high DNI levels and growing power demand.

China has made ambitious plan in CO2 emission reduction and pollution reduction. Developing renewable energy is key to achieve these goals. Both solar PV and wind energy have experienced their golden ages and are still growing fast. In August 2014, Chinese government announced plans to promote CSP power generation in China. Investors and project developers regarded this as the beginning of the CSP power market in China. Yet the local developers are either lack of the technology or experience in developing CSP projects. This presents huge opportunities for the foreign CSP companies.

Some Israeli CSP technology companies recognize the opportunities and seek to penetrate the Chinese market. This paper explores the market potentials of three Israeli technologies: HelioFocus's HelioBooster, aiming the existing fossil-fueled power plants; Tulip hybrid system from AORA-Solar; and the tower system from BrithtSource (though BrightSource is an American company, its technology was first developed in Israel). These three companies all have their own strengths and disadvantages. Most of all, they are all young companies; have numerous barriers in bringing their technologies into the market and succeed.

While China represents a huge opportunity, it has various challenges on its own, from geographical barriers to the lack of clear policy. Both the technology companies and the Chinese government need to make more effort on their own side in order to pave the road for the development of CSP projects. To enter the Chinese market, working with a local partner is crucial due to the heavily policy-oriented nature of the renewable energy industry. It may also become necessary if China follows its policy on the wind energy. During 1996 to 2000, China set the local content requirement at a minimum of 40% for wind farm projects, which was later raised to 70% in 2005, as an effort to develop local manufacturing capacity and encourage local investments (power-technology.com 2011). Localized manufacturing can be beneficial to both sides in reducing the cost, which in return help increase the competitiveness of CSP technologies.

There are studies exploring the solar thermal potentials in China, but there are no studies that look into the potentials of these particular CSP technologies developed in Israel and how they could fit into the Chinese market. Two of the three companies covered in this paper, AORA-Solar and HelioFocus, are very young startups. It is hard to predict how much further they can go given the current CSP market unshaped and its future unclear. Yet it is important to give enough attention to these companies, not only because of their unique technologies but also because they represent the current state of the majority startup companies in the renewable energy industry: enormous investment in both time and R&D, huge potentials with huge risks.

FOCUS OF THE MASTER PROJECT

This paper focuses on the opportunities and barriers faced by both the Chinese government and the three Israeli CSP technology companies. The first half of the paper analyses the particular characteristics of the Chinese CSP market. The current state of the China's power market is also included. The second half is devoted to the market potentials of each company, including their advantages and challenges. In order to better understand the difference in these technologies and the different segments of the market they can serve, a comprehensive description of the technologies are also presented.

METHOD

The analyses covered in this paper are derived from sources below:

Interviews:

Meetings at both the offices and project sites in Israel were conducted in August 2014. Valuable insights over the policy, operational performance and technology development came from interviewing both the managerial teams and onsite engineers.

Database:

The technological parameters of the technologies are primarily retrieved from the public sources of these companies, including data from existing projects. The companies also provide part of the data during the interviews and emails. Primary data includes: installed capacity (MW), capacity factor, annual output, water consumption, land use and installed cost ($/kW).

A summary of the current coal-fired power plants in China is used as base calculation to develop models in analyzing the market sizes. This summary includes all the large operational coal-fired power plants in China with their installed capacity and number of operating units. All the power plants are grouped into each province/region. Then the provinces are further categorized based on their DNI levels. The exact date of the summary is unclear, yet matches closely to the current status of the Chinese power market.

The DNI map from SolarGIS is used to identify the potential locations for CSP projects. Other maps that help understand the unique case of the Chinese CSP market include the China altitude map, annual precipitation map and the national grip map. A number of diagrams for explaining the technologies are retrieved from the companies' websites.

Based on the data and info collected, models are constructed for each technology to explore its market potentials, including total installed capacity by 2020, power output, land use and overall costs. For HelioFocus and BrightSource, scenario-based analysis is presented to simulate the difference in market size under difference circumstances.

1. WHAT IS CSP?

There are two major forms of solar energy in power generation, Solar Photovoltaic (PV) and Concentrated Solar Power (CSP). Solar PVs convert photons directly into electricity while CSP utilizes sunlight as a heat source, together with other components to generate power.

CSP normally features concentrating a large area of sunlight to a small area for high-temperature steam or air, depending on the designs. The heat generated by CSP systems can be used in power generation and other industrial processes, including seawater desalination, solar air-conditioning and Enhanced Oil Recovery. Power generation by CSP technologies is the main focus of this paper.

Currently, there are three major CSP technologies: parabolic trough, tower system and sterling dish system. There have been hybrid systems developed combining two different systems.

Parabolic Trough:

Figure 1: parabolic trough. Source: www.dlr.de

So far, parabolic trough is the most mature technology among these three. The typical structure of a parabolic trough features a linear parabolic reflector, which reflects light onto a receiver positioned at the central focal line of a reflector. The receiver is a tube containing working fluid, typically oil or molten salt, which is heated up to 150-350^{o}C (Martin, Goswami 2005). This high-temperature working fluid is then used to generate steam for power generation. There are number of existing fossil-fueled power plants in the world that incorporated parabolic trough solar field as an attempt to lower the primary fuel consumption.

Though being the mostly adopted CSP technology, parabolic trough has encountered fierce competition from CSP tower system, PVs and wind energy during the past decade. Solel - an Israeli CSP company acquired by Siemens at $418 million in 2009, went bankrupt when China dumped low-cost PV panels into the market (Wesoff 2013). In a parabolic trough system, the working fluid has to travel in distance to heat up the water, which results in great heat loss (Mohanmad, Orfi, Alansary 2013). Moreover, curved glass is utilized in the most cases, but they are more expensive than flat glass, and maintenance is labor-intensive. Especially in dusty areas, cleaning the reflecting mirrors is not necessarily an easy task and very time consuming.

Tower System:

Figure 2: Tower System. Source: US DOE, retrieved from www.energy.gov

Tower system has been receiving more and more attention, notably the largest CSP project in the world, Ivanpah Power Plant in California, consisting of three towers with a total net capacity of 377MW (total capacity is 392MW). One of the major components of a CSP plant is heliostat (reflection mirrors or lenses). These mirrors reflect huge amount of sunlight to a receiver positioned on a tower to generate high temperature steam or air, which can reach 1000^{o}C (Martin, Goswami 2005). This steam is then transferred to a nearby generating unit for power generation. The number of heliostats used is often large, in thousands or tens of thousands. The Ivanpah Project installed more than 170,000 mirrors for their three towers (BrightSource). The size of each mirror can be very large. In Ivanpah project, each mirror is the size of a garage door and there are two of them mounted on a steel frame, supported by a post (BrightSource).

The tracking system is one of the most important features in a tower system. Each heliostat is connected to the tracking system through cables (Ivanpah used 1200 miles of cables) (Overton 2014). These mirrors can adjust their angles individually through the tracking system, following the move of the sun to maximize the amount of sunlight they reflect to the heat receiver.

Often in a large CSP plant natural gas is used to further boost the temperature and stabilize the power production when the sunlight is insufficient (Wesoff 2012). So this kind of CSP power plants can be regarded as hybrid.

Though the currently installed tower systems have received some criticism because the power output did not meet the expectation, it is expected to grow rapidly as its development is still in its early stage and has room to improve. Most importantly, CSP tower power plants can be built with economical storage capacity, which can provide stable utility-quality electricity to the grid. Molten salt is the most common media in storing the heat, which continues generating heat for hours after the sun goes down. One common molten salt is a multicomponent $NaNO_3$-KNO_3, which is relatively cost-effective and abundant in supply (Flueckiger, Yang, Garimella 2013). This storage capacity is one of the biggest advantages of CSP technology over PVs and wind energy.

Dish Stirling:

Figure 3: Dish Stirling. Source: Stirlingenergy.com

A dish stirling is a stand-alone system. A parabolic reflector concentrates light onto a receiver positioned at the focal point of the reflector to generate high temperature working fluid. Air is the most common working fluid for power generation in a Stirling engine. Unlike the tower and parabolic trough systems, the distance of the reflector and the receiver is very short in a dish Stirling system. This design results in a higher solar-to-electricity efficiency (can reach to 30%) (Sandia 2008).

The modular design of a dish system allows flexibility in land use, power output and finance availability. They are more suitable for small-scale power production, thus often without storage capacity. Due to its intermittent power output and flexibility in size, sometimes people compare dish stirling to solar PVs. In this sense, dish stirling still can not compete with PVs due to its high cost.

2. CSP Vs. PV

Concentrated solar power and PV generate electricity through different mechanisms. They also behave differently. Solar PVs work relatively efficiently in cold conditions with ample sunlight. This is because PV cells can only utilize a range of wavelengths of sunlight, the visible spectrum and part of infrared (solarcellcentral). Radiation of too-low-energy or too-high-energy cannot be utilized to produce current, instead, it is transformed into heat, which affects PV efficiency and life span (solarcellcentral). CSP utilizes the entire electromagnetic energy spectrum from the sun and works more efficiently in hot conditions.

Putting the policy and regulatory framework side, CSP and PV can co-exist to serve different loads from a pure technological point of view. In fact, there are solar power plants being built using both CSP and PVs. Ideally, these two forms should complement each other instead of compete against each other. However, due to their different stages in technology development, market maturity, prices, and policies, they both have their own particular advantages and disadvantages.

CSP possesses the following favorable merits:

Grid-friendly

Power generation from solar PV and wind energy without storage capacities are not consistent, thus impose huge pressure on the grid. The current battery storage is expensive. So they cannot serve base load. CSP power plants can store energy more economically, thus capable of delivering utility quality electricity to the grid with stable generation (Odendall 2014).

Environmental-friendly materials

The major materials used in CSP projects are cement, steel and glasses, which have less negative impacts on the environment, compared to PV panels. Some researchers regard PV panels as the next generation e-waste, as they contain some key elements in common, including silicon tetrachloride, cadmium, selenium, etc (Mulvaney 2014). This can become a major issue when PV panels enter retirement stage and considerable amount of panels need to be disposed.

Higher efficiency potentials

Currently solar PV has an average efficiency of 15-16% while solar thermal can reach to 20% or even beyond (Detwiller 2013). Considering solar CSP development is still in its early stage, the room for further improvement is significant (Carlson 2009).

Diversity in design

There are a few different CSP technologies with existing products. CSP technologies are also used in different industries other than power generation, including enhanced oil recovery and desalination. Some CSP technology can generate both electricity and heat as byproduct for other purposes.

However, CSP is not perfect.

Water consumption

At the end use stage, solar PVs consume very little water (mainly cleaning). For large-scale CSP tower systems, power generation still relies on the traditional configuration of boilers, turbines and coolers to generate electricity, thus large quantity of water is required. The water usage is challenging, as most of the CSP projects are located in deserts where water is scarce. Air-cooling can reduce the water consumption but has a higher cost than water-cooling system.

Less flexibility

PVs can be installed on marginal lands with almost any range of power output. They can be implemented by all end users; including homes, retailors and industrial users. However, CSP power plants are often large projects, requiring vast flat land and most suitable for utility scale power production. This also prevents the wide adoption of CSP products.

Absence of simplicity and higher maintenance

PVs are easier to install and easier to use. Thus there are suitable to any individual users who lack the knowledge and experience in this product. This is especially beneficial for the remote and less developed rural areas. One panel breaks, the rest still generate electricity. Whereas, CSP technologies are built on a whole system with different parts and each of these parts are crucial. If the turbine or generator out of function, the whole system shuts down.

There is very few maintenance required for PVs except cleaning. It is easier to clean PV panels as they are normally lined on lower frames. There have been products specially designed for cleaning the panels automatically (a mechanic arm installed at one side of a ray of PV panels and slide across the panels on a rail). For CSP systems, the maintenance work relies on the professionals that are often scarce in remote regions. The cleaning is gruesome for large CSP projects which utilizes tens of thousands of heliostats. Cranes are needed to clean large mirrors and there are no machines available to replace the human labor.

Early stage of development

After decades of development, PVs have reached its economy of scale. The technology is mature and prices have significantly dropped, which make it very competitive. However, CSP market is not yet mature and CSP projects are extremely capital intensive. The required policy and regulatory framework is not widely adopted either.

Environmental critics:

Though all the renewable energies have impacts on the environment one way or the other, solar thermal power happens to be at the center of criticism, notably the bird casualty in Ivanpah CSP plant.

3. POWER GENERATION IN CHINA

China is the largest power producer in the world. Both of China's thermal power capacity and the hydropower capacity are the largest in the world (eia 2013). The majority coal-fired power plants are concentrated in the populous east, central and southern China while the majority hydropower comes from the water-affluent southwest. Before the ultra high-voltage transmission line was built that connects Xinjiang and Henan, Xinjiang province and Tibet were isolated from the rest of national grid. These two provinces are remote with vast land, less populated and less developed economically.

Wind is the largest renewable source after hydro and is developing rapidly (GWEC 2014). This is largely thanks to the Chinese government's policy during the early stage of wind energy. Chinese government mandated at least 40% of the components of a wind project come from domestic source (Kuntze, Moerenhout 2013). This number was raised to 70% in 2009, aiming to create and develop the domestic market and manufacturing capacity (Kuntze 2013). China is also the largest producer of solar PVs in the world. It is a well-developed industry with over 400 companies (Berry 2014). Chinese PVs were dominating the PV market with its low price. But China is also plagued with overcapacity and the producers are struggling with shrinking profit margins.

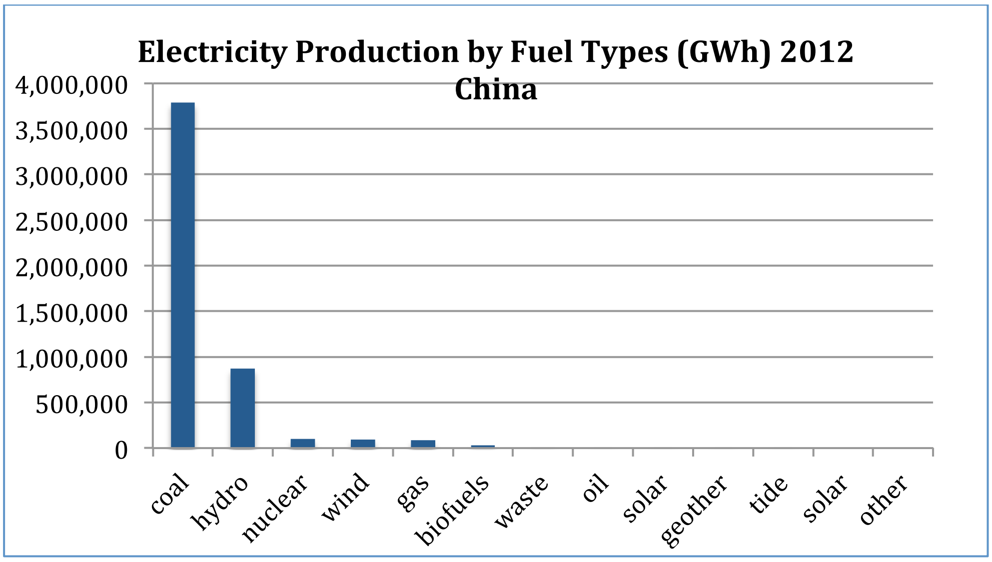

Figure 3: Electricity production by fuel types 2012 China. Source: IEA

The Chinese power market is highly regulated. The five major utilities in China: China Guodian Corporation, China Datang Corporation, China Huaneng Group, China Huadian Group and China Power Investment Corporation, are all state owned. Together they dominate half of the total power generation with each has about 10% (Muirhead 2014).

Coal-fired power plants

Coal is cheap and abundant in China. China is ranked No.1 in both coal production and coal consumption in the world (IEA 2014). By the end of 2010, China's proven coal reserves were estimated at 114.5 billion tonnes, representing about 13% of the total global reserves (IEA 2014). There are more than 2000 coal-fired power plants in China. At the end of 2012, the total installed capacity for power generation in China reached 1,144.9GW, of which 758 GW came from coal-fired power plants. In 2010, 66% of the electricity production came from coal-fired power plants in China (Huang 2013). This share will drop to about 50% by 2030 (Huang 2013). But the absolute consumption of coal will be more than double that of 2010. Coal has been in the past and will continue to be the dominant energy source for China (IEA 2014). It is challenging for the coal-fired power plants in China to reduce the emissions while meeting the growing demand.

Ultra-supercritical power plants:

So far, China has the largest number of ultra-supercritical power plants in the world (IEA 2014). Since the first 1 GW ultra-supercritical coal-fired power plant was built in Zhejiang in 2006, there have been more than 100 units of orders for 1 GW ultra-supercritical units built (Finkenrath, Smith, Volk 2012). A few other countries, including the U.S. and Japan, also made plans to develop advanced ultra-supercritical power plants with steam temperature above 700^{o}C (Huang 2013). Shanghai Waigaoqiao Power Plant is among the earliest ultra-supercritical power plants developed in China. It is equipped with 2*1000MW ultra-supercritical units and is designed to operate at a net efficiency of 41.6% (IEA 2012). The capacity factor of this plant reached 75% high by 2011 and achieved actual efficiency of 44.5% (IEA 2012).

Hybrid power generation with coal and renewables:

China has not developed any policy or plan regarding the possible implementation of integrate renewables into the existing coal-fired power plants. Yet this hybrid approach could have huge potential in China, benefiting both existing and planned coal-fired power plants. Including renewables could reduce the coal consumption and reduce carbon emission on a per kWh basis, while coal stabilizes the output requirement. Any large-capacity coal-fired units, which already have the generating facilities in place, can absorb the fluctuations associated with renewable sources.

Renewables can be included to the planned plants at the very beginning of design phase: select the most suitable renewable source, calculate the ultimate mix of coal and renewables, and allocate the land and finance needed. Among the total 473 young (<10 years) and large (>300MW) coal-fired power plants in the world by 2010, 390 of them were in China (IEA, 2012). This is translated to about 69% of the total operating coal-fired power plants are younger than 10 years in China; meaning these large generating units will continue to operate for at least 20 years in the coming decades (IEA, 2012). Power plants lose efficiency and require more downtime as aging (older plants need to burn more coal for the same power output). Moreover the environmental regulations will have to be more stringent in the coming years to deal with the pollution issue. Renewables could play a positive and crucial role in these power plants.

4. CSP DEVELOPMENT IN CHINA

China has started CSP researches in the late 1970, but the development has been seriously lagged since. Lack of financial support, the development of technology, materials, components and other supporting technologies had been abandoned. This situation was not mitigated with the fast growing PV industry in China. Compared to the well-developed solar PVs and their low price, CSP did not have any room for existence in China during the past decade.

With the growing pollution issues in China, during the recent years, the Chinese government has made ambitious goals in carbon emission mitigation and pollution reduction. Introducing more renewables into the energy mix is one crucial step in this plan. Given that the energy market in China is heavily policy oriented, how CSP projects will move forward largely depends on the government policy in terms of financial incentives and the goal for installed capacity. Currently, NDRC (National Development and Reform Commission) is in its last year of the 12th Five year plan (2011-2015) on Renewable Energy Development, which is targeting an installed capacity for solar thermal power plants of 1GW for 2015 and 3 GW for 2020 (Shanha 2012). It is unlikely that the 1GW goal will be achieved by the end of 2015.

Though the capital market has shown huge interest in CSP development, there are not enough projects to draw experience from and lack of a better understanding of the technologies, cost and electricity prices. Without the guidance of the government policy, both investors and producers choose to wait and see. Feed-in-tariff is one of the biggest unknown factors. The industry is speculating FIT could be within the range of 1.2RMB to 1.25RMB/kWh ($0.19 to $0.20/kWh) and is probably based on each case (Wang 2014). China issued standards for FITs for PV and wind power generation in 2013 and 2009 accordingly; both took the case-by-case approach. PV and wind energy markets experienced their golden ages ever since the release of the FITs.

Another issue that may hinder the CSP development in China is its significant initial cost. Currently the initial investment for CSP project is around $4000-$9000/kW, which is still significantly higher than PVs (Galarraga 2011). The progress of solar thermal power industry will need the support of the government in providing attractive financial packages, which will stimulate investment from the capital market. The secretary of the National CSP Technology and Innovation Union, Liu Xiaobing, stated that the CSP market would need 3.5 billion RMB ($564.5 million) support from the government in order to reduce the current LCOE of CSP projects from 1.38RMB/kWh ($0.223/kWh) to 1.15RMB/kWh ($0.185/kWh) (PV-Tech 2013). And to further reduce to 0.6RMB/kWh ($0.097/kWh) to compete with coal-fired plants, a total of 30 billion RMB ($4.84 billion) will be needed (PV-Tech 2013).

In theory, for CSP projects the cost per kWh will decrease with the increase of installed capacity. In another word, it is more cost effective to build large solar thermal power plants than small ones. However, the CSP systems are much more complicated than PV in terms of the diversity of available technologies, structures and components. Furthermore, CSP development is still at its early stage, an accurate comprehensive evaluation of the cost is hard to reach at the moment. CSP market is developing at a relatively slow pace worldwide. This results in a slow decline in cost than otherwise.

The China CSP League recommended four strategic steps for CSP development in China. First step is to build experimental CSP power plants, aiming to discover suppliers and understand the systematic procedure. Second step is to build demonstration power plant, set up initial supply chain. The third step is to scale up the CSP projects, improve the supply chain and reduce cost. The final step is to commercialize CSP po`wer plants, form a competitive market without subsidies from the government by 2025 (Li 2010). Currently China CSP industry is moving to demonstration project stage from experimental stage.

First Commercial CSP Project in China

Delingha Qinghai: 50MW, FIT: 1.2 RMB/kWh

The first CSP project connected to national grid in China is located in Delingha, Qinghai province by SUPCON Solar (Zhongkong Solar). With capacity of 50MW, the total investment was 996 million RMB (Gu 2014).

This project uses a tower of more than 90 meters high. More than 20,000 heliostats are controlled by a central system, called “chasing the sun”, to maximize the amount of sunlight received by the mirrors (Gu 2014). In a constant fight against the wind, sand and some extreme weathers (can reach minus 35 Celsius), this project has been operating smoothly since its installation. The first phase of 10MW was installed in July 2013 and has been supplying electricity to grid since. Once the project completes, the annual electricity output will reach 121,000 MWh per year, enough to power 80,000 homes (Gu 2014).

Note that the first CSP project that received permission was a 50-MW parabolic trough project in Erdos, Inner Mongolia in 2011. However it was never been built. The producer, Datang Energy, bid for this project at 0.9399RMB/kWh ($0.15/kWh), which is too low to ever be profitable (camdapower 2014).

Domestic industry players

Shanghai Electric Group formed a joint venture with BrightSource, focusing the construction of utility-scale CSP plants in China.
Sanhua Group invested $15 million in HelioFocus in exchange of 30% share, entering solar thermal market.
Zonghangdongli invested more than $15 million in stirling engine production and demontstration projects.
Xiangdian Group acquired SBI – Stirling Biopower Inc, an American stirling engine producer.
Shouhangjieneng invested more than $10 million, entering CSP EPC.

5. CSP POTENTIALS IN CHINA

Increasing power demand:
China had surpassed the United States to be the largest power producer in 2011, with an estimated total generation of 4,476 TWh (EIA 2014). According to EIA's projections, power generation in China will reach 7,295 TWh by 2020 and 11,595 TWh by 2040, almost triples the level in 2010 (EIA 2014). It is estimated that nearly 75% of China's electricity consumption comes from the industrial sector (thegenerator 2014). Installed capacity is expected to steadily grow over the next decade in order to meet the growing demand, particularly in the eastern and southern China where large urban areas concentrate (thegenerator 2014).

China Net Electricity Generation by Fuel, 2010 – 2040 (TWh)

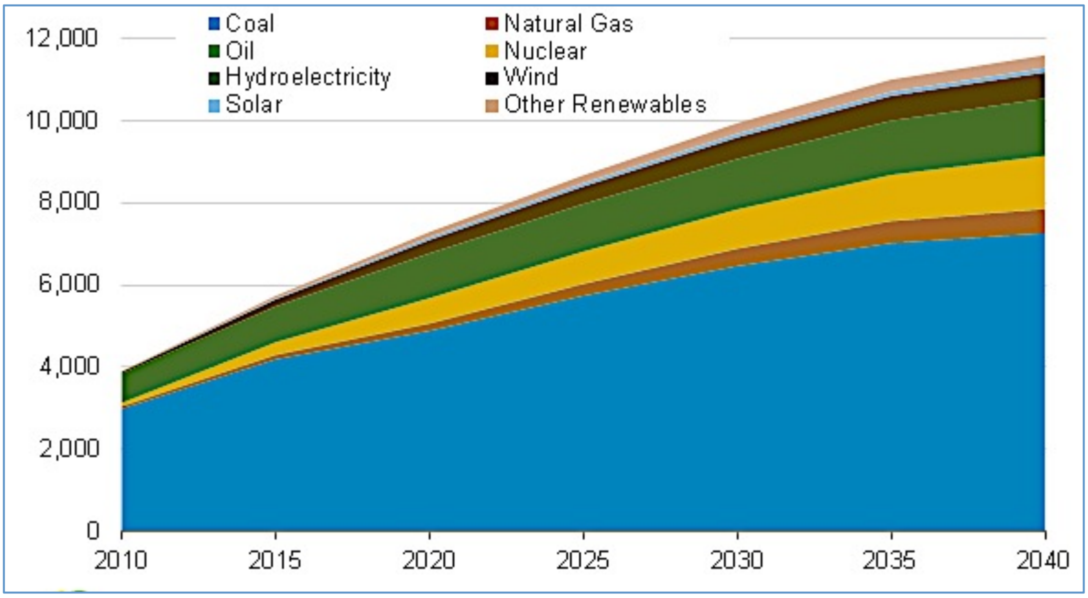

Figure 5: China net electricity generation by fuel 2010-2040.
Source: U.S. EIA, International Energy Outlook 2013.

High DNI levels:

Direct Normal Irradiance (DNI) is the amount of solar radiation received per unit area of a surface that is positioned perpendicular (or normal) to the rays coming in a straight line from the direction of the sun at its current position in the sky (Abu-Hamdeh, Alnefaie, 2014). The more radiation a surface receives, the higher its DNI level. That is why the heliostats are designed to chase the sun to maximize the heat they receive. DNI is the one of the most important indexes for CSP technologies.

A GIS study conducted by Black and Veatch estimates that China has 16,000 GW of potential suitable for CSP applications (<3% slope and DNI above 5 kWh/m2-day); higher than both USA and Spain with potential of 15,000 GW and 720 GW respectively (ACEII). Provinces with most potential due to abundant sunlight and low population concentrations (in descending order) are listed below:

- Neimenggu (Inner Mongolia, north)
- Xinjiang (northwest)
- Qinghai (northwest)
- Xizang (Tibet, southwest)
- Gansu (northwest)

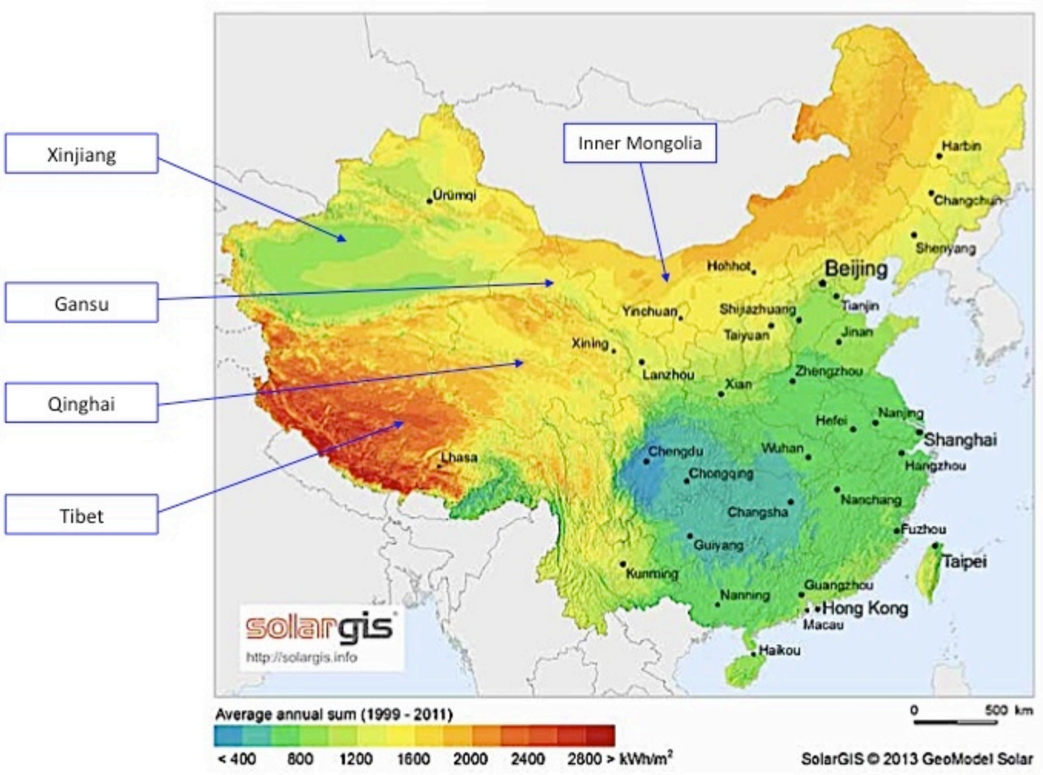

Figure 6: China DNI map. Source: solargis.com

For these provinces, large-scale tower CSP power plants are most suitable in open lands. However, a hybrid solar power system can also help reduce the pollution and coal consumption in the coal-fired power plants close to the cities. In terms of the east coats and the southern China, modular dish systems with high efficiency might be viable in supplying extra heat for existing fossil-fueled power plants.

	5-6 kWh/m2-day		**6-7 kWh/m2-day**		**>7 kWh/m2-day**	
Province	GW	TWh/yr	GW	TWh/yr	GW	TWh/yr
Inner Mongolia	6000	15000	59	170	0	0
Xinjiang	4300	11000	400	1100	340	1200
Qinghai	2000	4900	720	2100	31	100
Tibet	320	770	300	860	1100	3900
Gansu	440	1100	15	42	0	0
Sichuan	56	140	0	0	0	0
Hebei	26	64	0	0	0	0
Shanxi	18	44	0	0	0	0
Shaanxi	9	21	0	0	0	0
Heilongjiang	7	17	0	0	0	0

Table 1: China DNI resources. Source: ACEII

Air pollution and CO_2 emission:

China feels the urgency of reducing fossil fuels more than any other countries. In some major cities, air pollution has reached to an unbearable level. It is sending millions of people to hospitals every year. Yet China is the largest coal consumer. In power generation, more than 70 percent of installed capacity comes from coal-fired power plants (IEA 2014). Chinese government has set ambitious goals, determined to cut down carbon emissions and aiming to provide 20% of total electricity from renewables by 2020 (Chadha 2014).

Base load demand:

In order to meet the growing demand and curb the air pollution at the same time, progressive policies will have to be implemented and billions of dollars will be invested in renewables. This represents huge opportunities for all the renewable sources. While PVs and wind power have experienced rapid growth, they cannot provide stable supply without economical storage facility. CSP power plants can provide utility quality electricity for base loads with their storage facilities.

Economy of scale:

CSP is still at its early stage in China with mostly demonstration projects. The market and supply chain are not yet mature. This presents huge opportunities for the producers for a whole new market as well opportunities to lower the overall cost of CSP components. It is estimated that the CSP power market in China can reach 100 billion RMB ($16 billion) by 2020 if the goal to be met according to the government's plan (powerbeijing 2011). It is also a great opportunity for some local manufacturers to upgrade and diversify their business to increase their competitiveness.

Benefits for supporting industries:

CSP projects consume considerable quantity of cement, steel and glass. China is the largest producer of all of these three materials and has been facing overcapacity issues during the past years, largely due to the slowdown in the construction sector (Davis 2014). China has been systematically shutting down factories in order to cut the excessive production. CSP projects can help digest these materials and benefit more industries with its longer supply chain. Ivanpah CSP project used 7,500 tons of steel and 36,000 cubic yards of concrete (equivalent to 66,237 metric tons) (Overton 2014). Use Ivanpah project's material usage as base calculation, there will be 57,340 tons of steel and 506,900 tons of concrete needed, should China achieve its goal of 3GW by 2020.

Other industrial implementation:

Besides the power generation market, CSP technologies can be used in seawater desalination and Enhanced Oil Recovery (EOR). In the 12th Five-Year Plan, the Chinese government announced a target of 2.2-2.6 million m^3/day of online seawater-converted capacity by 2015 to ease the increasing water demand and water scarcity (People's Daily 2012). Several EOR pilot projects are also being implemented.

Political environment:

The particular political environment could help accelerate CSP development in China. Once the Chinese government decides to solve a problem, radical changes take place, for both of the good and bad of it. PV industry is a good example. It experienced rapid growth with the push of the government; it also generated huge overcapacity, causing destruction in the market, which eventually pushed the largest domestic PV producer to bankruptcy. Both the Chinese government and the developers would need to take cautious steps in developing CSP projects in China.

Foreign investment:

In terms of opportunities for international players, Chinese market cannot be missed. It is huge and dynamic. A common path to develop projects in China is to form a joint venture with a local partner, who will deal with the permit issue, land leasing, regulation, local employee management and government relations.

6. CHALLENGES IN CSP IMPLEMENTATIONS IN CHINA

High altitude (cold winters):

Unlike the CSP projects sites in USA and Spain, the most suitable locations for CSP projects in China have very high altitude (the average altitude in Qinghai is 3000 meters and 6000 meters for Tibet). Though they received abundant sunlight during the day, the temperatures can easily drop to -30^{o}C at nights during the winter. This wide fluctuation of temperature requires extremely resilient design and materials.

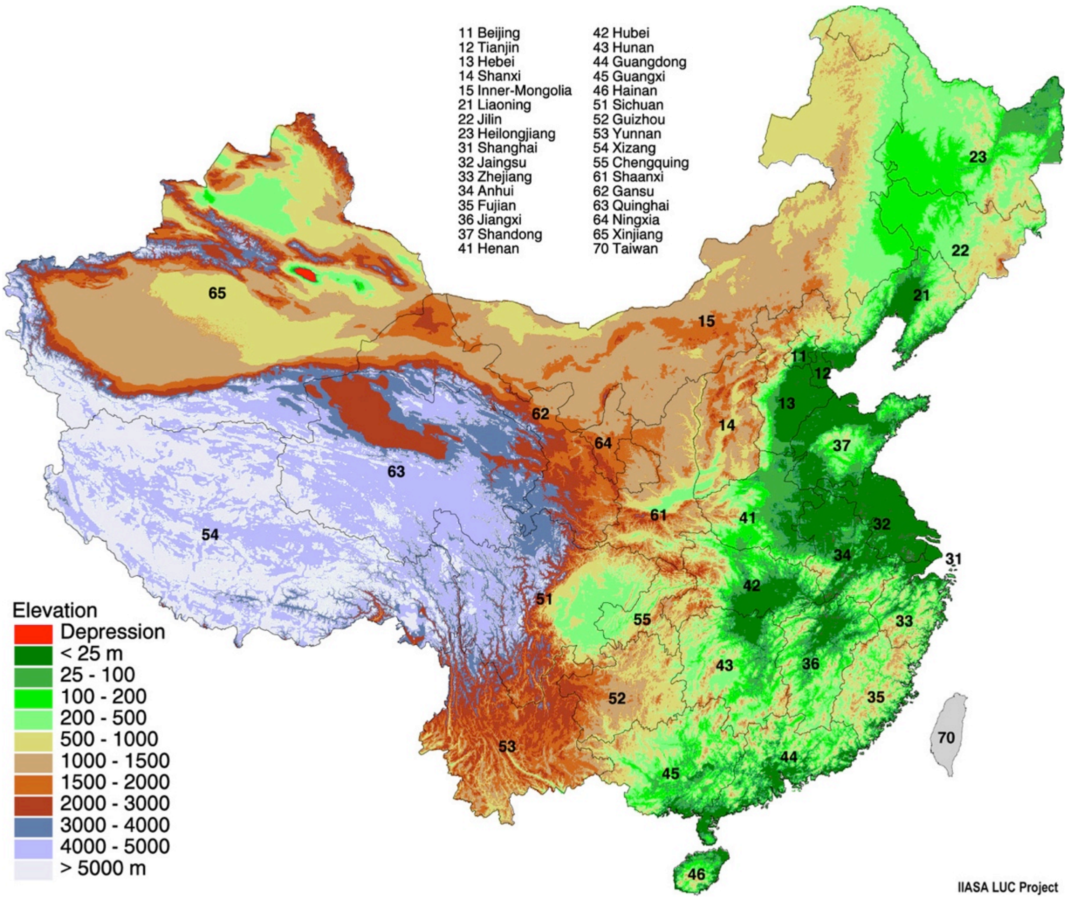

Figure 7: China terrain and altitude map. Source: U.S. Geological Survey, EROS Data Center: GTOPO30 Digital Elevation Model.

Water consumption:

CSP tower systems consume considerable amount of water. This is one of the major environmental issues CSP technologies have to deal with. Use a 50MW water-cooling CSP power plant as reference; the annual water consumption is about 1,600,000m^3 (Wu, Hou, Chang 2014). This includes the water used to generate steam, cooling and cleaning the heliostats. Air-cooling can reduce the water consumption to 400,000 m^3 but would incur a higher installation cost (Wu 2014). The project developers need to find solutions to secure water supply while avoid depleting the precious underground water resources.

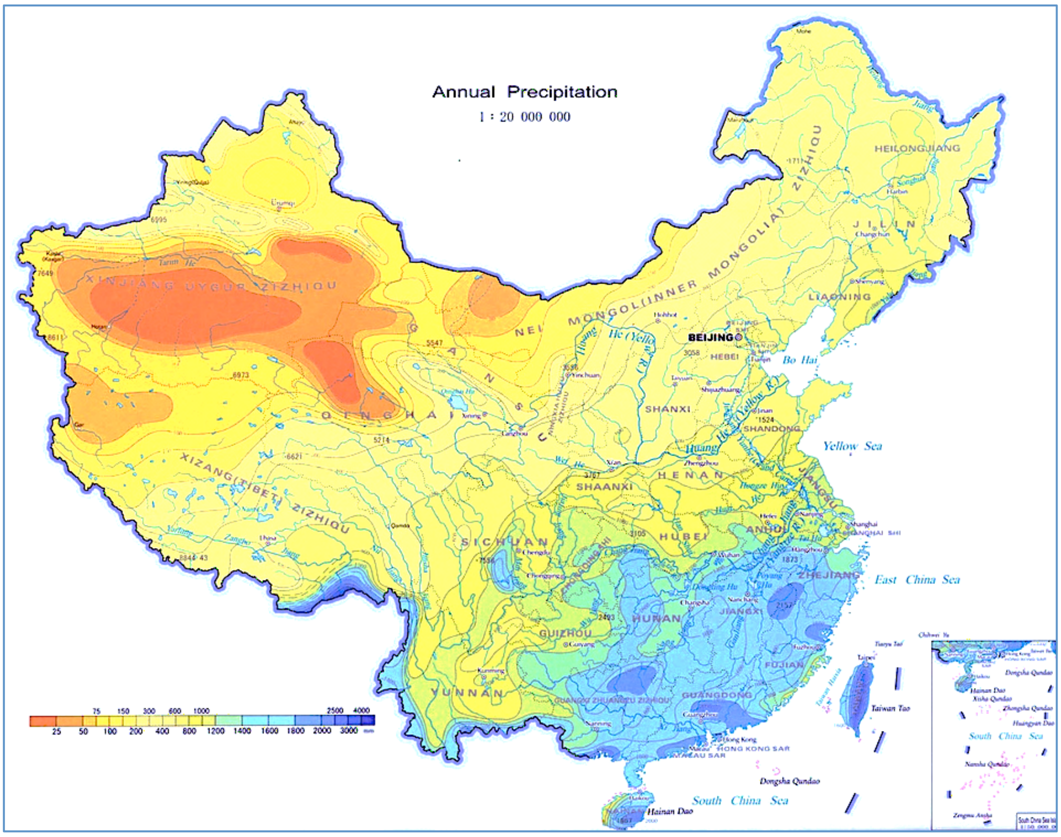

Figure 8: China annual precipitation map. Source: chinampas.

Limitation in long distance transmission capacity:

China needs to build more high voltage and ultra high voltage transmission lines to deliver the power generated from the north and west to the populous east and southern China. Tibet and Xinjiang have rich solar thermal resources, yet the limited transmission lines present huge challenges in power transmission.

The east coast, southern and central areas are lack of fuel for power production while the majority coal production is from the west and north. The transportation of coal presents huge cost and often hit its bottleneck while the majority hydropower locates in the southwest. Without sufficient effective transmission systems, the power supply from the west cannot quench the thirst for power along the east and south regions.

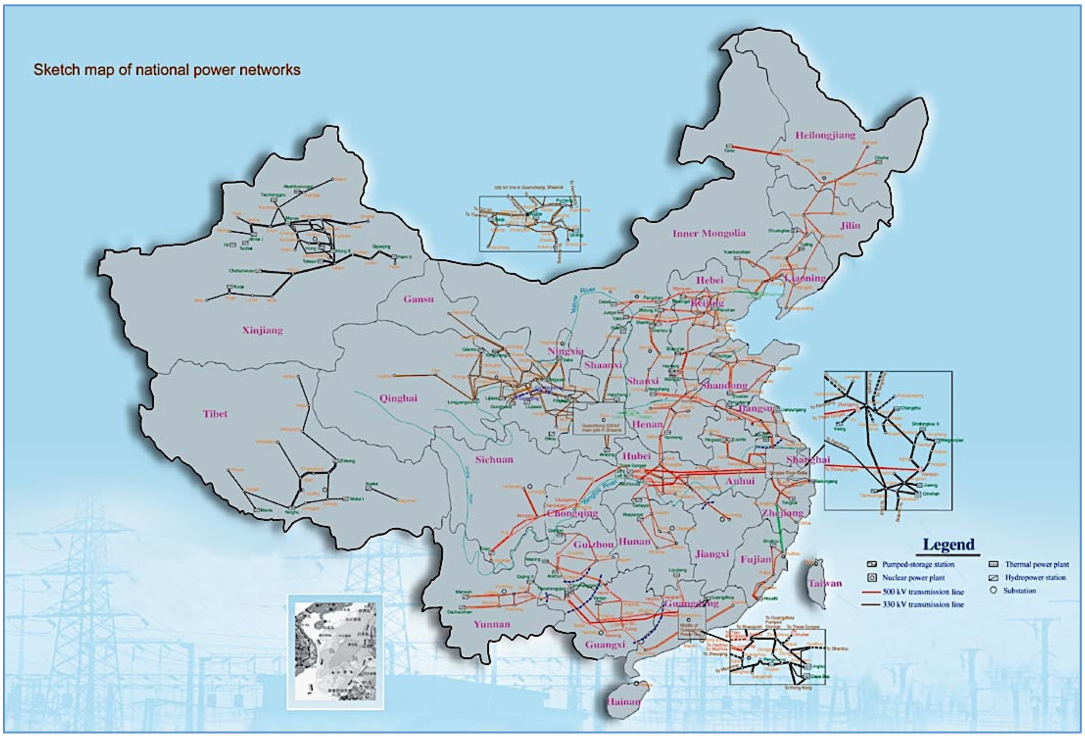

Figure 9: China power grid map. Source: sp-china.com/powerNetwork/gridmap.htm

China started building ultra high voltage transmission lines only a few years ago. Since then, vast investment has been planned for the further development. The size of the future CSP market will highly depend on the pace of the development of these transmission lines in China.

Connecting points	Distance km	Voltage kV	Capacity MW	Completion time
Jindongnan-Nanyang-Jingmen	654	1000	5000	Dec, 2011
Yunnan-Guangdong	1373	800	5000	June, 2010
Xiangjiaba-Shanghai	1907	800	6400	Junly, 2010
Jinping-Sunan	2095	800	7200	Dec, 2012
Huainan-Shanghai	1298	1000	8000	Sep, 2013
Hami-Zhengzhou	2192	800		Jan, 2014
Nuozhadu-Guangdong	1413	800	5000	Sep, 2013
Xiluodu-Zhejiang	1680	800	8000	July, 2014
Zhejiang North-Fuzhou	1206	1000	6800	March, 2015

Table 2: Current Ultra High Voltage transmission lines completed and under construction in China by 2014. Source: Wikipedia

Sand and dust:

The western (Xinjiang, Qinghai) and northern (Inner Mongolia) have large deserts. Sand storms and dust are ubiquitous. The heliostats are very sensitive to the dust. Studies show that in a dusty CSP project site, the efficiency of the power production can drop by 12% if the mirrors are left upswept for three weeks (Sarver, Qaraghuli, Kazmerski. 2012). Currently there is no efficient way of cleaning the mirrors. The heliostats producers worldwide are working on dust resistant finishes on the mirrors.

Absence of a clear price policy:
FIT for CSP power generation is not clear. Investors cannot move forward without a reasonable FIT price. Government loans would also need to be in place to get the private sector involved. Currently there are three banks involved in financing CSP projects in China: Bank of China, Asia Development Bank and World Bank.

Immature market:
The CSP power market is not yet established. The domestic components producers and project developers are lack of experience. CSP projects are capital-intensive and the decline in cost is unlikely to be fast as it takes years for the market to reach economy of scale.

7. MARKET ANALYSIS: HELIOFOCUS

HelioFocus
Solar Thermal Solutions

Founded in 2007, HelioFocus specializes in providing thermal solutions for conventional utilities and any other thermal industries. They focus on the heat collection segment instead of the whole system, thus well suits any planned or existing power plants as supporting heat source (HelioFocus 2015).

HelioBooster:

Steam augmentation system

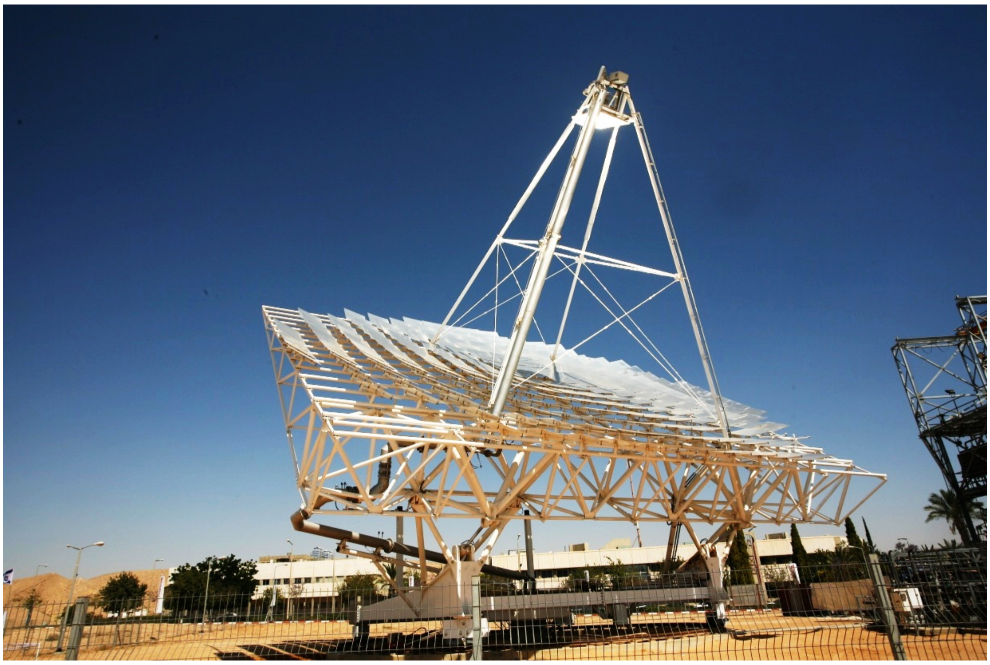

Figure 10: HelioBooster. Source: heliofocus.com

This system was designed primarily to supply solar thermal energy to any existing power plants, including coal-fired power plants and combined circle power plants as the supporting heat source. The idea is to replace part of the fossil fuel consumption with solar thermal to generate steam in conventional power plants when solar energy is available. It supports peak conditions as well as base loads. One can regard a fossil-fueled power plants with HelioBooster installed as hybrid. Other implementations include desalination and EOR in providing heat for steam generation.

High efficiency and high working temperatures are achieved with high concentration ratios (>1:2000). This unit can be installed on fragmented land with up to 5% slopes (HelioFocus 2014). Its modular design enables small-scale installations (up to 10MW) through medium scale installations (10MW – 50MW) up to large-scale installations (>50MW); and allows existing installations to be expanded when land and finance allow (HelioFocus 2014).

The working fluid, air, is pressurized and capable of reaching 1000^{o}C and can generate up to ultra-supercritical temperature steam (USC; i.e >620^{o}C)

(HelioFocus 2014). It maintains a stable output of steam temperature and steam pressure under changing solar conditions, along the day. In an existing fossil-fueled power plant, HelioBooster can lower the fuel consumption without compromise the power output. This is equivalent to reduce the overall emission.

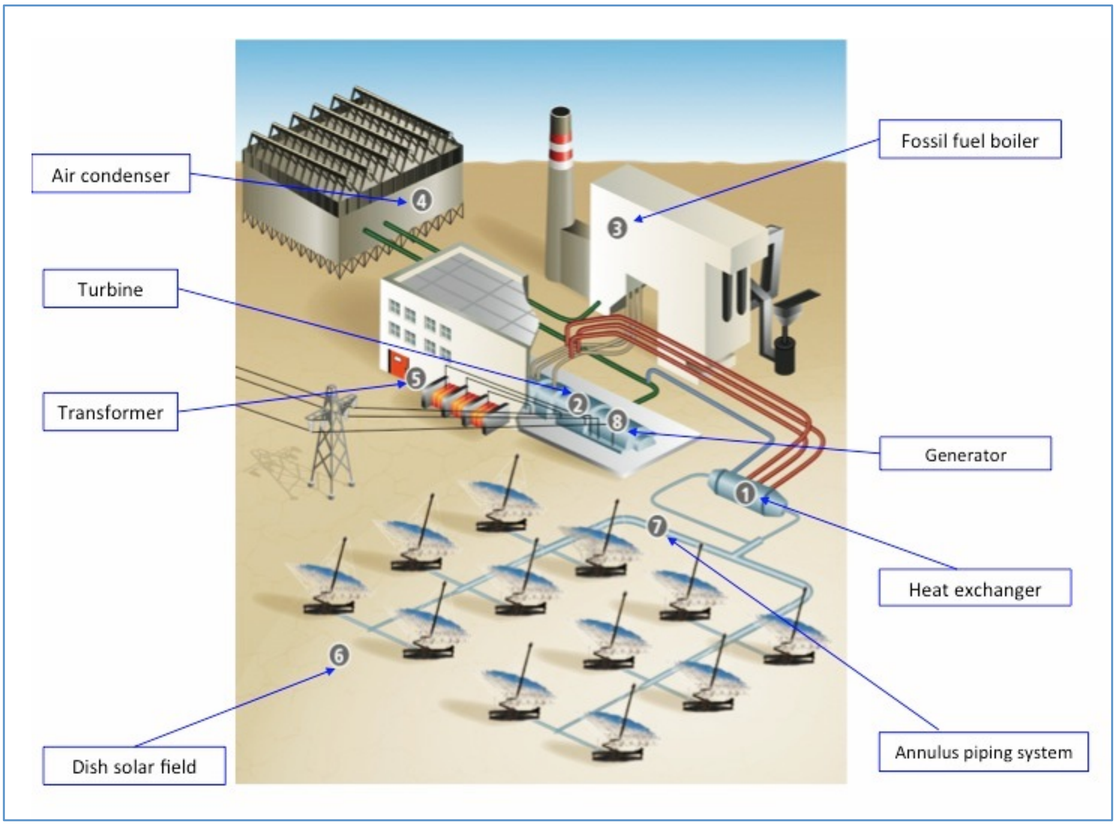

Figure 11: HelioBooster Diagram Source: Heliofocus.com

There are three major components in this system: heliostats, heat receiver and the heat exchanger.

Heliostats:

For each unit, there are 225 pieces of small size mirrors mounted on the steel structure with a total working surface of 500m^2. This configuration makes the assembly easy to execute and cheaper to produce (the seamless configuration is very hard to achieve for this size). All the mirrors work as a whole, reflecting sunlight to the receiver. The steel frame is mounted on supporting posts, which sit on a circle shape rail (turntable & drive). The whole unit can rotate along the rail and adjust the angle of the mirrors along the posts. Each heliostat can be controlled individually through the central tracking system from afar.

Heat receiver:

The heat receiver is their key technology. Positioned at the focal point of the dish, the heat receiver heats up the intake cooler air with the heat reflected from the mirrors, and then sends the air to the heat exchanger to heat up the water. This high temperature air requires very resilient materials.

Unlike the tower system that the heliostats are placed very far away from the receiver, the mirrors of a HelioBooster are very close to the receiver, thus results in a higher efficiency in collecting the heat (concentration ratio of solar energy >2000) (HelioFocus 2014). The air goes through the heat receiver is heated to a very high temperature very shortly. The heat receiver can alter the volume of the intake air to adjust the air temperature. The more air comes in, the lower the temperature it goes. The air flows back to the receiver after heating up the water to minimize heat loss.

Heat exchanger:

Through well-insulated pipe, the heated air from each unit is pumped to the heat exchanger; a tank built with layers of metal and insulation materials. The piping is double jacketed, double insulated to enable transferring hot air of 650^{o}C and cool air of 150^{o}C (HelioFocus 2014). This is another key design of this system. Inside the heat exchanger, water running through tubes is heated up to generate steam for power generation.

Establishment in China

SANHUA CO.,LTD invested $15 million in HelioFocus for 30% of equity during the past 4 years. A 1MW boosting demonstration site is being built for TAIQING Solar Thermal Power Co. in Inner Mongolia northern China (HelioFocus 2014). In 2013, they signed a memorandum of understanding to install 200MW HelioBooster units to boost coal-fired power plants in Inner Mongolia. The project has an estimated value of 340 million dollars.

Market potentials in Chinese market

Opportunity:

The sheer number of large coal-fired power plants in China and growing air pollution problem present opportunities for HelioBooster system. Introducing solar thermal into the existing coal-fired power plants can lower the coal consumption, CO2 emission and other pollutants while maintaining the power output. The modular design allows flexibility in land use within the existing power plants. Regions with satisfactory DNI levels (≈ 1400) are considered sufficient to use this system due to the high solar concentration ratio of HelioBooster. To estimate the potential market size for HelioBooster, models are built to estimate the possible land use, power output and cost associated with the installed capacity of HelioBooster. The idea is to replace certain percentages of the existing installed capacity from coal-fired power plants with HelioBooster.

Data: Performance Parameters of HelioBooster

The parameters of HelioBooster's performance are drawn from the company's base assumption of a 300MW coal-fired power plant in Inner Mongolia, China.

Coal-fired power plant in China (Steam: 530C, 83bar)	MW	300
HelioBooster installed capacity	MW	15
HelioBooster Capacity factor in China (Solar Valley)		28%
Filed net collecting area	m2	61,000
Filed external dimensions	m2	183,000
Normal steam operationg tem.range	Deg C	up to 620
Ambient operating temperatures	Deg C	- 20 to +60
Useful life expectancy	years	25
Annual energy delivered	MWh/year	31,000
Annual emmision reduction	Ton CO2/year	12,243

Table 3: HelioBooster parameter data. Source: HelioFocus

Data: coal-fired power plants in China

The data were drawn from a summary of coal-fired power plants based on regions (major cities and provinces) in China. The regions are then categorized into four groups based on their DNI levels (DNI levels are estimated based on DNI map from solargis.com). Some regions including Tibet are somehow missing. But it does not affect the model much as the installed capacity in Tibet is small.

Group by DNI level	DNI (annual kWh/m2)	Province / region	Capacity MW	Total Capacity MW	% of total capacity
1 Excellent	2200	Qinghai	2,075	134,910	16.6%
	2200	Inner Mengolia	108,880		
	2000	Xinjiang	8,575		
	2000	Gansu	15,380		
2 Good	1600	Heilongjiang	18,385	208,780	25.6%
	1600	Jilin	20,630		
	1600	Ningxia	30,470		
	1400	Yunnan	12,400		
	1400	shannxi	18,360		
	1400	Liaoning	26,700		
	1400	Hebei	39,050		
	1400	Shaanxi	42,785		
3 Possible	1200	Beijing	2,360	344,686	42.3%
	1200	Tianjin	12,469		
	1200	Fujian	24,782		
	1200	Shandong	39,455		
	1200	Guangdong	48,258		
	1000	Hainan	3,812		
	1000	Shanghai	16,544		
	1000	Zhejiang	39,660		
	1000	Henan	44,105		
	1000	Anhui	46,685		
	1000	Jiangsu	66,556		
4 Poor	900	Jiangxi	17,210	126,235	15.5%
	800	Guangxi	15,820		
	600	Chongqing	9,240		
	600	Hubei	18,700		
	600	Sichuan	20,560		
	600	Hunan	21,365		
	600	Guizhou	23,340		
		Total	814,611		

Table 4: China Coal-fired power plants capacity and DNI categories.

Group 1 – Excellent DNI Level

Regions under group 1 have excellent solar thermal source, representing 16.6% of total installed capacity of coal power plants in China. Group 1 is optimal to install HelioBooster, especially Inner Mongolia, which has a total capacity of 109 GW, alomost 54 times of Qinghai's total capacity. Inner Mongolia is one of the major coal reserves in China and the base of a few major polluting industries. It has been suffering from severe desertification and deforestation. Coal mining has caused large-scale land collapse, threating the lives of the habitants. Another factor that makes Inner Mongolia urgent to reduce coal consumption is that it is located right above Beijing. The pollution and sand dust blow to Beijing all year round, causing suffocating air pollutions. Though Beijing has built a band of trees aiming to block the sand dust, it is so far ineffective and avoiding the fundamental causes.

Group 2 – Good DNI level

DNI levels under group 2 are also suitable, but will have lower efficiency and capacity factor than group 1. These provinces are concentrated in the northeast and central north China. Within this group, Hebei, Shannxi and Shaanxi are among the top polluting provinces in China, largely due to their long history in coal mining and heavy industries, including steel and cement, both consume large number of coal. Notably Hebei province envelops Beijing and Tianjin; and is the largest steel producing province in China. A considerable portion of air pollution in Beijing comes from Hebei. It is more urgent for this group to reduce coal consumption and air pollutions.

Group 3 – Possible

Group 3 is most advanced economically, but the implementation of HelioBooster is questionable due to its low DNI levels though Beijing, Tianjin and Shandong can be a potential market. Most provinces under group 3 are along the east cost, where population, manufacturing industries, economic growth and pollution concentrated. With HelioBooster's current cost and efficiency, it is not attractive enough to the investors. While the installation cost can drop with local manufacturing, the efficiency improvement needs longer time to achieve.

Group 4 is not considered due to its poor solar sources.

Models

Four sensitivity analysis models are constructed to simulate the changes in installed capacity, land use, power output and cost. The capacity factor takes a wide range of values, based on the assumptions that higher DNI and longer sunlight availability result in a higher capacity factor. Land use (m2/MW) also fluctuates because the number of units required for 1MW differs with different DNI levels (higher DNI requires fewer units per MW capacity). Installation cost ($/kW) varies as well because the cost will likely to drop significantly with increasing local manufacture and economy of scale.

Most of the models only include group 1 to replace part of the installed capacity with HelioBooster. The assumption is based on China's plan to install 3GW by 2020. Currently the total capacity of group 1 is 134,910 MW. That means replacing 2.2% of this value already reach 3GW and it is unrealistic to think that HelioBooster will be the sole player in Chinese CSP market. The replacement percentage (of group 1) from 0% to 1% (0GW to 1.35 GW) is a more realistic range, which makes it hard to include other groups. However, it is necessary to explore the possibility of including group 2 and 3 into the simulation, given these two groups face more immediate pressure in pollution reduction.

A summary based on the models is displayed below, simulating three possible scenarios. In calculating the total value (cost of installation), an average of 1200$/kW is used for all three scenarios. The assumption is that a decreasing installation cost will increase the demand, but it is hard to predict the price at the moment; giving different cost to each scenario will also defeat the purpose of estimating the difference in its market potential. The average capacity factor in the Optimistic scenario is lower than the Realistic scenario because the Optimistic scenario includes regions from group 2, which has lower DNL levels.

Scenarios of HelioBooster development by 2020						
Scenario	Replacement of Group 1	Replacement of Group 2	Replaced Capacity (MW)	Annual Power Output (GWh)	Total value ($ million)	CO2 reduction (million ton/y)
Optimistic	1%	0.2%	1,767	3,877	2,120	1.47
Realistic	0.6%	0	809	1,844	971	0.73
Pessimistic	0.3%	0	405	780	486	0.31

Table 5: HelioFocus scenario summary.

Conservatively speaking, one-billion-dollar revenue is foreseeable (accumulative by 2020) if HelioFocus were to steadily grow in China. It is not unthinkable that the market share for HelioFocus could reach two billion dollars, if China pushes a much bigger target by 2020.

Partnership with SANHUA

HelioFocus benefits from this partnership in two aspects. First, they target China as one of the biggest markets. Israel has abundant solar energy, but the market is too small. The stage of CSP development in China echoes that of HelioFocus in that both have huge potential yet both are still in the early development stage.

Second, HelioFocus could benefit from SANHUA's manufacturing capabilities. SANHUA is the leading manufacturer in Air-con components in the world. They have rich experience in establishing supply chain and localizing production, which will significantly lower the production cost and increases HelioBooster's competitiveness. Export is possible in the future. In terms of government relations, SANHUA has rich experience in engaging local authorities, which is crucial in renewable industry in China.

From SANHUA's perspective, this partnership allows them to enter renewable market. China manufacturing sector is facing huge challenges. Labor costs and labor scarcity are increasing, which have pushed large number of mediocre factories out of business. To survive, the Chinese manufacturers have to upgrade and diversify their operation. Contrary to the traditional industries that stagnated, renewable industry is growing fast backed with strong policies and future plans of the government. Instead of spending years in R&D, it is more efficient to invest in an existing technology and enter the market with it.

Another factor that might have contributed this partnership is the entrepreneurial spirit they share in common. SANHUA started as a small family business while HelioFocus was founded by a couple of ambitious scientists. It is possible that this experience helped these two parties form trust and understanding.

Challenges

HelioFocus is in a critical stage in commercializing their technology. Currently their first demonstration site is being built in China. It takes time for the Chinese government to materialize the policy. And HelioFocus will have to go through the growing pain along the learning curve, which takes both time and patience. In terms of the technology itself, HelioFocus needs to continue improving its performance in order to penetrate wider market, especially group 2 and group 3 where the DNI levels are not very high yet need to reduce coal the most.

Another challenge is the maintenance, particularly cleaning the heliostats. Regions under group 1 have high DNI level, but they are covered with vast desert and dust accumulates very fast. The reflecting mirrors need to be cleaned often to maintain their efficiency. Instead of using one or two large mirrors, each HelioBooster unit utilizes more than 200 of small size mirrors (about $2.2m^2$ each), which are separately mounted on a huge tall steel frame. To clean the hundreds of mirrors on each unit can be gruesome and time consuming, which potentially incurs higher the maintenance cost.

8. MARKET ANALYSIS: AORO-SOLAR

AORA-Solar is a developer in solar-biogas hybrid power technology that specializes in small-scale off-grid solutions. Their technology was developed in Weizmann Institute of Science and then was licensed to AORA (AORA-Solar 2014). So far they have two active sites and they are in the negotiation with the Ethiopian government for possible solar development in Ethiopia.

TULIP Hybrid System

Distributed solar thermal:

Figure 12: AORA Tulip System. Source: AORA-Power

Combining tower and stirling in design:

AORA's DST unit is a combination of tower and stirling engine system. From the appearance, it is easy to confuse this system with the tower system. Though it collects heat from sunlight in the same way as the tower system, the heat is used to heat up air instead of water to push a micro turbine for power generation.
On the top cabin of the tower, the micro turbine and the heat receiver are placed side by side. This is different from the tower system that in a traditional tower system, the turbine and generator are located on the nearby ground and only the heat receiver and boiler are placed on the top of the tower.

At the moment AORA imports these micro turbines from Turbec, an Italian producer. These micro-turbines have a maximum capacity of 100kW, which set the upper boundary of power output. The key component in this system, the heat receiver, is AORA's own technology. They have been testing different materials for higher temperature allowance. So far they can operate with air of 1000°C (AORA-Solar, 2014).

The tulip shape of the tower is not solely for aesthetic purpose. The ball shape top allows enough space for both the turbine, the receiver and room for maintenance. The post (stem) is very slim and stabilized with steel strings rooted on the ground. This design minimizes the shadow of the tower casting on the heliostats.

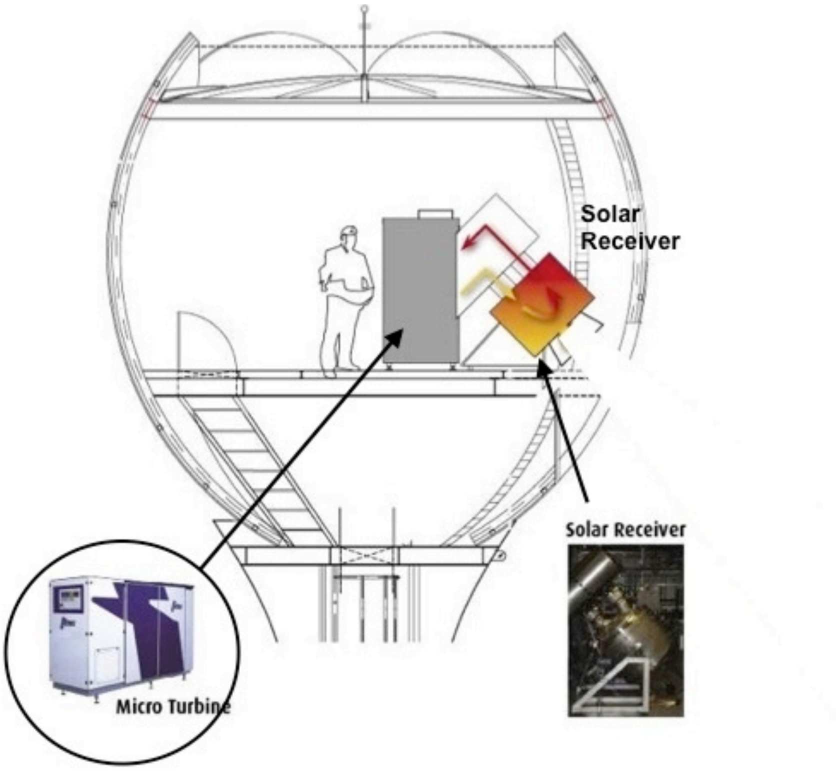

Figure 13: AORA Tulip diagram. Source: AORA-Power

Hybrid and 24 hours supply:

Tulip is unique in that it is hybrid and can supply uninterrupted energy 24 hours a day. The engine can work on multi fuels, including both renewables and fossil fuels. During the sunny daytime, sunlight is the main heat source to heat up the compressed air for power generation. During the night, it still can continue generating electricity with natural gas, biogas, diesel or any fuel available.

The demonstration site in Samar desert is designed to utilize the biogas produced by the nearby cattle farm and biomass from the palm tree residuals when there is not enough sunlight. In this sense, this system is ideal for remote small-scale, off-grid applications, but it is also suitable to supply power to the grid if the power production is secured day and night.

Water consumption:

Water is used to clean the heliostats. Tulip barely consumes water during power generation. When the temperature is above 35°C, the engine needs water for cooling at a rate of 230 L/MWh, which is very small (AORA-Power 2014).

Modular design:

The modular design allows flexibility. Each unit is capable of generating electricity alone and separately from the others. Once the community grows, a second unit can be easily added. This also means that there will still be power supply even one of the units breaks and shuts down. This system occupies small piece of land with each unit requires only 3,500 m^2 (AORA-Solar 2014). The Tulip system also produces 170 kWe of heat as a waste product. This extra heat can be used for many applications, including heating water for domestic use, industrial (desalination), assisting biogas generation and institutional use.

Central tracking system:

The heliostats are controlled by a central tracking system, which can be controlled from afar. This design requires minimum onsite personal. For example, the site in Samar desert is controlled by an operator in the Tel Aviv office that is 300 km away. There are only two staff assigned on the site (one is enough, the second is for backup). An application is developed that allows the onsite operator to adjust the mirrors remotely. The development director stated that they could even operate the sites abroad from their office. Each heliostat can adjust its angle individually to track the sun for maximum sunlight. The tracking system also records massive data including real time DNI for each heliostat. The data is crucial in improving the design and efficiency of the system.

Active sites

Kibutz Samar, Israel is the site of AORA's first CSP prototype module. It serves as the testing ground and simulating the conditions of other sites. Currently it is not connected to the grid. Another site is located in Almeria Spain, the largest science park designed specifically to the R & D of solar-based power generation systems in Europe (AORA-Solar 2014). The project was completed in 2011.

Establishment in China:

AORA has no operation in China so far.

Market potentials in Chinese market

AORA's Tulip system posses a few key merits, particularly its minimum water usage, hybrid and flexibility in fuel options and modular design, however, it would encounter a few challenges if they are to enter the Chinese CSP market as power generator.

Financing challenges:

The Tulip system is well suitable for remote, off-grid areas with abundant sunlight. In China, areas without access to electricity are normally very poor. Even with the government's help, it is hard to image they would receive one million USD just for one unit for one village. There are about 4000 villages in China still off the grid, which means a total of 4 billion USD required if this system is to be installed in each of these villages (Xinhua 2014). It would be more effective to invest this sum to extend the grid to these villages rather than building separate system. To compare the cost of Tulip with PVs, it cannot compete against PVs. The installed cost for PVs in China can go below 1500 $/kW. Tulip is not favorable with its 5000 $/kW installed cost.

Geographical limitations:

A large number of areas without access to the grid are in the western China. Though these regions have very high DNI levels, they also have high altitude. Anywhere above 1000 meters, the efficiency of the gas turbine will reduce quite substantially to below 80% (AORA-Solar).

Another challenge is that a lot of villages are scattered, which means sometimes there are only a few families living in one village. Their total electricity demand might not be sufficient enough to require a whole system. Also what makes Tulip unique is its hybrid capability, but the alternative fuels (gas, diesel, biogas, natural gas, etc.) might not always be available in these areas. Internet accessibility might be another barrier as the heliostats rely on Internet to be controlled afar.

Complexity in operation:

Unlike PVs producing electricity in a straightforward manner, Tulip is a delicate system and requires all components work as a whole for power generation. If a few PV panels break, the rest panels continue generating electricity. This is not the case with Tulip in that one segment's malfunction will lead to shutting down the whole system. Maintenance probably will not be immediate as these regions are remote and poor that it is unlikely they could afford a technician onsite.

Investor preference:

Chinese developers (both private and government) love big projects. If a product is too niche, it is hard to attract the local developers. The local government also prefers big impressive projects, as normally these projects are big showcases to both the public and the central government.

Security concern:

Tibet and Xinjiang provinces are large and spread out. They have large number of villages still off-grid. Yet these two provinces are sensitive areas with increasing turmoil and tension causing a lot of attention from the central government. It is more likely that the government would like to see a centralized grid connecting to these villages rather than having independent power generation within these villages.

Opportunities

AORA could target the industrial sector in China. Their key technology lies in the heat receiver, not the turbine. The system can operate air at 1000^{o}C. This could be really valuable in industries like desalination, mining, oil extraction and any industry needs high temperature working fluid. The industrial sector is also able to afford this system. Its capability in providing both heat and electricity at 24/7 is particularly ideal in mining industry.

Models

Two models are built based on the parameters below (provided by AORA). One is to explore the annual output (electricity only) with changes in the capacity factor due to the difference in DNI levels and the number the units operating. The rather small engine used in this system does not permit a high productivity. Ten units of Tulip System with capacity factor of 26% produce less than 2.3 GWh of electricity (installation cost of then units is 5 million USD). Another model explored the change in installed cost $/kW. Though it is anticipated to have a lower cost, it is hard to predict the pace, depending on how fast the production can scale up and where they will be produced.

Cost of one unit (electricity output only)	$500,000
Cost of one unit + biogas digester	$1 million
Electricity output capacity	100kW electricity + 170 kWe thermal
Installed cost	$ 5/W
Powering capacity/unit	60-80 homes
Assembly configuration	Modular
Operating mode	Hybrid (sun only, sun + fuel, fuel only)
Potential operating hours	24/7 (hybrid mode)
Footprint	3500 m^2/unit
Installation time	6 months
Operational water consumption	230L/MWh (when temperature is above 35°C)

Table 6: Tulip parameter data. Source: AORA-Solar

9. MARKET ANALYSIS: BRIGHTSOURCE

BrightSource Energy is based in Oakland California. Ranked as one of the top 10 greentech startups in the world in 2008 by Greentech Media, BrightSource specializes in designing, building, financing and operating utility-scale CSP power plants (Greentech Media 2008). It has attracted investors including Google.org, BP Alternative Energy, Morgan Stanley, Black River, etc.

Tower system

The way BrightSource's tower system produces electricity is the same as the conventional power plants. The difference lies in the heat source and storage facility. The tower system uses the heliostats to reflect sunlight to the heat receiver, which is positioned at the top of a tower in the center of the heliostats field. The heat collected by the heat receiver then heat up the water to generate high temperature steam, which is then channeled to the nearby generating components (turbine and generator).

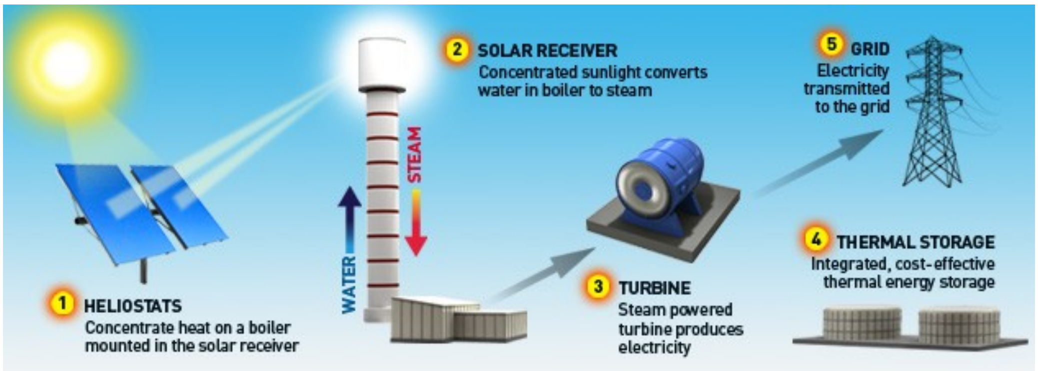

Figure 14: BrightSource tower system diagram. Source: BrightSource

Besides the generating components in a conventional power plant, the tower system also includes a few other key parts: heliostats field (controlled by the optimization/control software), the tower (with boiler and heat receiver), and the storage facility.

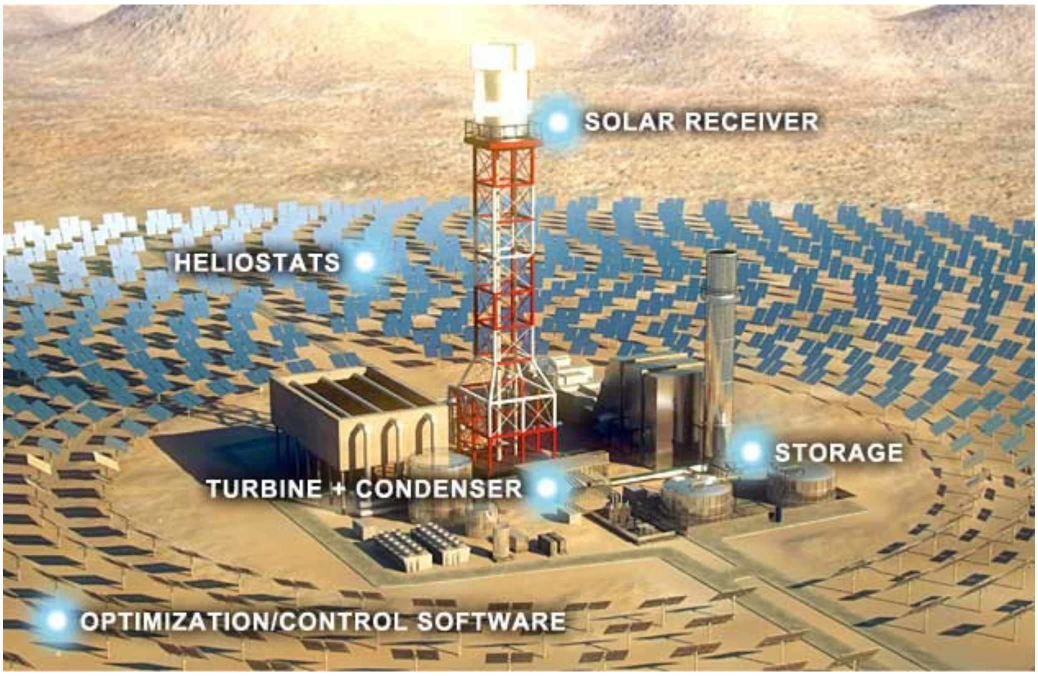

Figure 15: BrightSource tower system. Source: BrightSource

Heliostats:

Two mirrors of the size of a garage door are mounted on a steel post and accurately positioned through GPS. They are able to withstand winds within 85 mph. The heliostats are controlled through optimization/control software to tracking the move of the sun in order to maximize the sunlight received.

During the night, all the heliostats are kept in "standby" position with the mirrors perpendicular to the ground, to minimize the dust collected on the mirror surface. The dust is a problem with the heliostats field as it is accumulated very quickly in the desert (decrease the efficiency); and there is no effective way of cleaning them currently. Human labor is required on a regular basis to clean the mirrors during the night.

All the heliostats are connected to the control system through cables. Ivanpah power plant used 1200 miles of cables (Overton 2014). At the testing site in Israel, BrightSource's engineers are testing to control the heliostats powered by a small PV panel attached to each heliostat, instead of through cable.

The tower:

The towers are steel structure. The boiler is placed on the top. A higher tower allows higher efficiency and reduces the footprint of the site. The towers in the Ivanpah power plant are almost 140 meters tall. BrightSource is about to construct a new project in Israel that is expected to reach 240 meters. The heliostats need to be regularly recalibrated to make sure the sunlight reflected on the receiver surface is even to avoid any damage by overheating one spot. Though sunlight is the primary source of energy, natural gas is used in the morning to boost up the water temperature and when the sunlight is not sufficient to ensure a stable power output.

Heat storage:

The tower system is normally built with large installed capacity, which is more cost-effective on a $/kW basis. For a large-scale tower power plant, storage facility is often included to extend the power production after sun goes down.

Molten salt (combination of KNO_3 and $NaNO_3$) is the common media in storing heat. The storage capacity extends the power plant's capacity factor (increase the total power output); allows more flexibility in power production in ancillary services; and stabilize power output, which is particularly important for grid connection. It is one of the key advantages of CSP system over PVs in that it allows less expensive energy storage capacity.

Ivanpah Project

BrightSource built the largest CSP tower system in the world, Ivanpah power plant in the Mojave Desert, California. The plant location receives abundant sunlight (annual average DNI is about 2700kWh/year); together with the vast flat land make it ideal location for CSP projects. This project is the first large-scale CSP tower system in the U.S. and thus far the biggest project funded by the Department of Energy's Loan Projects Office (LPO), a total of $1.6 billion.

Featuring three towers of a total capacity 392 MW (net capacity is 377MW) and 173,500 heliostats, this project has a total cost of $2.2 billion (Overton 2014). PG&E and Southern California Edison are contracted to purchase 975GWh/year from Ivanpah power plant (Overton 2014). It is expected to produce electricity enough to power 140,000 homes in California during the peak hours of the day (BrightSource). This project uses air-cooling to reduce its water consumption, which is crucial in water-scare desert. The water, withdrawn from two wells on the site, is purified and primarily used for boiler and mirror cleaning (BrightSource).

Environmental disputes:

The project partners spent almost $35 million in protecting and relocating the tortoises during construction, including the purchase of 7000 acres land as tortoise habitat (Overton 2014). The heliostats supporting posts are directly mounted into the desert soil in order to minimize the land destruction. However, despite the effort to minimize the impact on the environment and the animal habitats, Ivanpah project has received enormous criticism. BrightSource encountered a few lawsuits from environmental organizations. Ivanpah project is accused of causing hundreds of birds casualty when the birds flying over the heliostats field. It is also reported that the glares from the heliostats field "blinded" the vision of pilots.

Plant performance and power output:

The power output has been significantly lower than it was expected. Since its operation from the end of December 2013 to Nov 2014, the three units generated 401,203 MWh, which is less than half of what it was anticipated (Pete Danko 2015). Though the power output has picked up since, it is unlikely that the projected output to be met in the short run.

To secure the power supply, Ivanpah sought permission to increase the natural gas usage by 60% with the ancillary boiler than was originally allowed under the plant's certification, which put a cap in natural gas consumption of 5% of total annual heat input from the sun (Pete Danko 2014). This request was approved in August. This has incurred some criticism of how "clean" the electricity is generated at Ivanpah. BrightSource claimed that the reduced output was due to the poor weather that was worse than expected. And they have anticipated that there might be some growing pains while working on this "one-of-a-kind project".

Ivanpah Power Output (MWh)

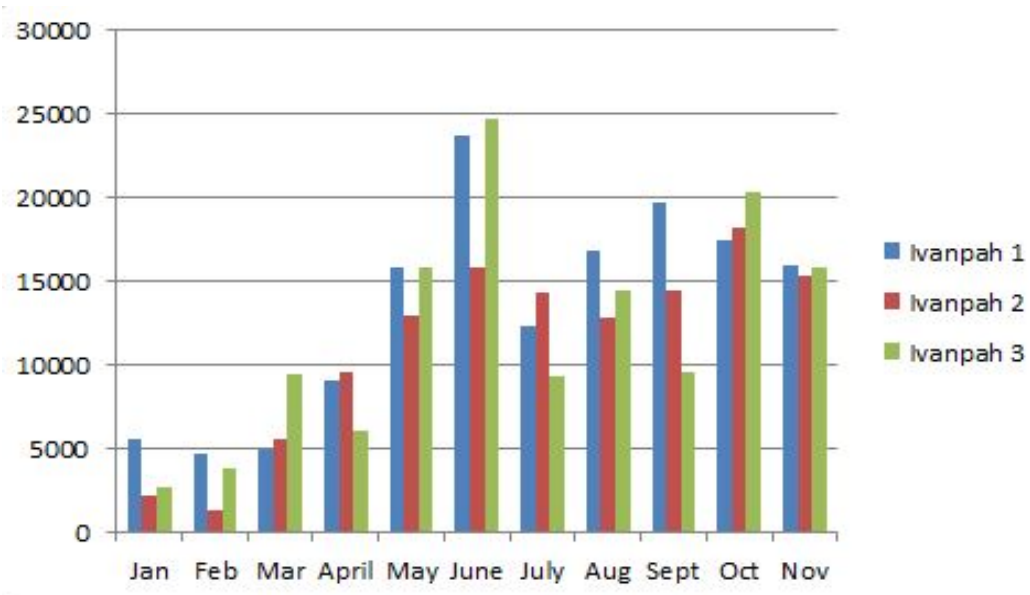

Figure 16: Ivanpah power output. Source: EIA

Establishment in China

In Nov 2014, BrightSource formed a joint venture with Shanghai Electric Group to build CSP plants in China (BrightSource 2014). Shanghai Electric Group, a leading power equipment-manufacturing group, has been ranked the world's No. 1 in market shares for 10 years (BrightSource 2014). The Chinese market became particularly important for BrightSource after the drawbacks that led to withdrawal of most projects in the U.S.

This newly formed joint venture has submitted their first proposal to construct two 135 MW CSP plants in Qinghai province. This is part of the first phase of the Qinghai Delingha Solar Thermal Power Generation Project, which aims to build six 135 MW CSP tower units (construction is expect to start in 2015 and complete in 2017); totaling 810 MW installed capacity (Jorge Alcauza 2014).

Market potentials in the Chinese market

BrightSource possesses a few desirable characteristics as a project developer that China would appreciate. For the size and projects portfolio of BrightSource, it is logical that large local corporation would seek partnership with them. Shanghai Electric Group has strong market influence in the Chinese market and strength in manufacturing, which is ideal for BrightSource to deploy projects in China. BrightSource is strong in design and building large project, which is exactly what Chinese government and local investors like.

Most importantly, they already built the largest CSP tower power plant in the world, which provides valuable experience that the new projects in China could learn from. This demonstrates credibility and enhanced the Chinese investor's confidence in BrightSource. The Chinese government and investors are more willing to make radical decisions. The local regulatory and legislation systems also make it easier to reach quick agreement and push operations forward. This is particularly important for large-scale projects, which usually take years to acquire the permits and finance arrangement.

Ideal locations are the provinces with high DNI levels located in the north and west China as mentioned earlier, including Qinghai, Xinjiang, Tibet, Gansu and Inner Mongolia. These areas have abundant sunlight and vast unoccupied land. They are also among the least developed provinces in China. Developing CSP projects not only provide clean energy but also provide jobs and economic prosperity. The local governments will be particularly welcoming large projects in order to increase employment and tax revenue.

In terms of the environmental dispute BrightSource encountered in the US, the Chinese market will be much "quieter", for the good and bad of it; the Chinese public will probably woe less over the cooked birds given that the public awareness over the animal wellbeing is not yet strong enough.

Models

Three models are developed to explore the possible land use, annual power output and market size of BrightSource in the Chinese CSP market. The total installed capacity is estimated based on the assumption that China is to meet its 2020 goal of installing 3GW CSP projects. BrightSource's current proposal of building two 135MW power plants is also taken into account. Data from Ivanpah project is used for the models.

In the scenario summary below, total projects value is estimated under two unit prices, indicating that the installed cost ($/kW) could vary significantly once the manufacturing localized. The installed cost of Ivanpah project is 5,612 $/kW and the first CSP power plant in China has an installed cost of slightly over 3000 $/kW. It is reasonable to expect the installed cost to drop in the range of 4000 to 3000 $/kW (too high, BrightSource wont be able to compete). The land use value is only for heliostats field, excluding the other components due to limited data.

In the optimistic scenario, a total 2GW installed capacity would have an accumulative market size of 6 billion USD with installed cost of 3000$/KW. The realistic scenario is to install 1GW by 2020. This is based on the assumption that BrightSource is able to build the 810MW project it has proposed and perhaps one more project for other client. If the installed cost is at 3000$/kW level, the accumulated project value can reach 3 billion USD. The pessimistic scenario is not necessarily "pessimistic", but rather a relatively lower capacity than the other two. 500MW is based on the assumption that BrightSource finishes the first two 135MW towers by 2017 and perhaps another tower by 2020. The projects value could reach 1.5 to 2 billion USD with the given installed costs. However, it is important to understand that the estimations could fluctuate widely given the past experience with the Chinese PV industry.

Scenarios of BrightSource development by 2020						
Scenario	Total Installed Capacity (MW)	Capacity Factor	Annual Power Output (GWh)	Total value million $ (Installed Cost 4000$/kW)	Total value million $ (Installed Cost 3000$/kW)	Heliostats land use km2 (6500 m2/MW)
Optimistic	2,000	28%	4,906	8,000	6,000	13
Realistic	1,000	26%	2,278	4,000	3,000	6.5
Pessimistic	500	24%	1,051	2,000	1,500	3.3

Table 7: BrightSource development scenarios.

Challenges

The water consumption of BrightSource's tower system can be a challenge. Though air-cooling can reduce the water consumption signifantly, water is still required to generate steam. Evaporation causes substantial water loss. In the ideal CSP locations, water scarcity presents a problem needs to be tackled.

Environmental issues are another problem; although it is unlikely BrightSource will encounter the same magnitude of scrutiny in China as it had in the US. BrightSource aims at the global market; and they cannot afford any bad reputation in any aspect. If their future projects cause huge environmental damages in China, BrightSource probably will not be welcomed in other markets.

Meanwhile, BrightSource needs to show improvement in its technology's performance. If the future projects in China also failed to deliver the expected power output like Ivanpah, it will face even more doubts and make it harder to expand to other markets.

10. Summary

Like any form of technologies in the world, CSP technologies are not perfect; yet they are constantly improving and possess huge potentials. CSP could help China meet its growing demand in the coming decade while curb CO2 emission and air pollution. Creating a domestic CSP market in China will not only help sustain the economic growth but also provide opportunities in digesting overcapacity along the supply chain. The Chinese government needs to make progress in providing the policy and regulatory framework in order to attract investment in CSP projects development.

Among the three Israeli technologies covered in this paper, HelioFocus was the first to enter the Chinese market. Aiming to replace part of the installed capacity from the coal-fired power plants, HelioFocus had a good start with its demonstration project built in Inner Mongolia. However, they would need to continue improve their efficiency in order to penetrate a wider market, especially in the central and east coast of China. If China is to meet its goal in installing 3GW CSP projects by 2020, HelioFocus could foresee an encouraging market share in the Chinese CSP power market.

AORA-Solar's Tulip unit is unique in its hybrid design, capable of utilizing multi fuels and generating electricity 24/7. It also consumes very little water, which is crucial in water-scare west and northern China. However, the financing and operational complexity might prohibit its development as a power generating units in the remote rural off-grid communities in China. In stead, I would recommend AORA-Solar to explore the industrial sector, where financing will be less an issue and a hybrid power generator with 24/7 supply will be much more appreciated.

BrightSource builds large-scale CSP power plants, which is very much favored by the Chinese government. Their partnership in China is also on a higher level, thus it is natural that their market size will be much larger than the other two. It is also crucial that BrigtSource already built the largest CSP power plant in the world that they can draw lesson and experience from. Potential locations for their future projects will be in the west and northern China, such as Xinjiang, Qinghai and Inner Mongolia with rich solar resource and vast unoccupied land.

Land use comparison:

The summary below is to illustrate the difference in land use of these technologies, assuming a CSP power plant with 100 MW installed capacity. Note that the land use for AORA is for complete systems while BrightSource and HelioFocus are for heliostats field only. This explained part of the reason why AORO would need much bigger land for the same capacity. Another reason causing this gap lies in the very design of AORA Tulip system, in that it is meant for small-scale community-based use.

Land use for 100MW installed capacity CSP power plant			
Company	km^2	Info	Implementation
BrightSource	0.66	Heliostats field only (based on Ivanpah project data)	Large-scale independent project
HelioFocus	0.83	Heliostats field only (assume 5dishes/MW)	Flexible in size, supporting existing power plants
AORA	3.5	Complete units (including generating components)	Small scale modular projects

Table 8: Land use summary

REFERENCES

A. Mohamad, J. Orfi and H. Alansary. (2013). Heat losses from Parabolic Trough Solar Collectors.

Abu-Hamdeh. N. H., Alnefaie. K.A. (2014). "The first Solar Power Tower System in Saudi Arabia", Applied Mechanics and Materials.

ACEII. The feasibility and policy study on developing concentrating solar power in China. http://aceii.org/EventAgendas/CSP%20in%20China_EN%20Summary.pdf

AORA-Solar. (2014). http://aora-solar.com/product/

Berry. C. (2014). Enough to go around? Raw materials and limits to growth in solar energy. http://www.pv-tech.org/guest_blog/enough_to_go_around_raw_materials_and_limits_to_growth_in_solar_energy

BrightSource. (2014) http://www.brightsourceenergy.com/technology#.VPubVWTF8jk

Camdapower. (2014). http://solar.camdapower.com/xingyedongtai/2014-07-14/133.html

Carlson, E. D. (2009). Basic science issues in the development of photovoltaic.

Chadha. M. (2014). Renewable energy share in China's power generation to reach 20% by 2020

ChinaDaily. (2013) http://www.chinadaily.com.cn/hqcj/zgjj/2013-06-25/content_9407496.html

Davis. B (2014) Pain spreads from China's excess production. http://blogs.wsj.com/chinarealtime/2014/07/16/pain-spreads-from-chinas-excess-production/

Detwiller. P. K (2013). As solar panel efficiencies keep improving, it's time to adopt some new metrics http://www.forbes.com/sites/peterdetwiler/2013/07/16/as-solar-panel-efficiencies-keep-improving-its-time-to-adopt-some-new-metrics/

EIA. (2014). http://www.eia.gov/countries/cab.cfm?fips=ch

eia.org (2013). Country analysis brief overview. http://www.eia.gov/countries/country-data.cfm?fips=ch

Finkenrath, M. Smith, J. Volk, D. (2012). CCS Retrofit. Analysis of the globally installed coal-fired power plant fleet.

Flueckiger. S. M, Yang.Z and Garimella SV. (2013) Design of molten salt thermocline tanks for solar thermal energy storage. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1191&context=coolingpubs

Galarraga, I. Markandya, A. (2011). Handbook of sustainable energy.

Greentech Media. (2008). Greentech Media's Top Ten Starups

Gu, C. (2014). http://scitech.people.com.cn/n/2014/0920/c1007-25699227.html

Gunther, M., Joemann, M., Csambor, S. Advanced CSP teaching Materials. Chapter 5: Parabolic Trough Technology

GWEC. (2014) Global wind energy outlook. http://www.gwec.net/wp-content/uploads/2014/10/GWEO2014_WEB.pdf

HelioFocus. (2014). http://www.heliofocus.com/technology-2/

Huang, Q. (2013). The development strategy for coal-fired power generation in China. http://cornerstonemag.net/the-development-strategy-for-coal-fired-power-generation-in-china/

IEA (2014). Coal in the Energy Supply of China. Report of the CIAB Asia Committee.

Jorge Alcauza, BrightSource to develop a massive 810 MW CSP complex in China. November 2014 http://www.csp-world.com/news/20141111/001411/brightsource-develop-massive-810-mw-csp-complex-china

Kuntze. Jan. Moerenhout, T. (2013). Local content requirements and the renewable energy industry – a good match?

Li, D. (2010). http://news.qq.com/a/20100930/000670.htm
literature, and mitigation approaches.

Martin, L. C, Goswami, Y. (2005). Solar energy pocket reference. Earthscan. p. 45

Muirhead, J. Brent, A. Hernandes, C. Hashem, H. Poliafico, Marco. Reaction, G. (2014). CSP Market Report 2014

Mulvaney, D. (2014). Solar energy isn't always as green as you think.

Odendaal. N. (2014). CSP players make case for increased role in SA energy mix. http://www.engineeringnews.co.za/print-version/csp-players-make-case-for-increased-role-in-sa-energy-mix-2014-10-29

Overton, W. T. (2014). Plant of the year: Ivanpah solar electric generation system earns POWER's highest honor.

People's Daily. (2012). http://article.wn.com/view/WNAT24008141a6c566a5a74cce1959593e1b/

Pete Danko, Ivanpah Solar plant picking up steam, Jan 2015. http://breakingenergy.com/2015/01/28/ivanpah-solar-plant-picking-up-steam/

Pete Danko, More problems for CSP: Ivanpah solar plant falling short of expected electricity production. October 2014 http://www.greentechmedia.com/articles/read/ivanpah-solar-plant-falling-short-of-expected-electricity-production

Power-technoloy.com. (2011). Snapshot: Renewable Energy – China's Imbalanced Trade. http://www.power-technology.com/features/feature119046/

PowerBeijing. (2011). http://www.powerbeijing.com/contents/124/8608.html

PV-TECH. (2013). http://www.cspplaza.com/article-2469-2.html

Sandia.gov (2008). Stirling energy systems set new world record for solar-to-grid conversion efficiency.

Sarver, T., Qaraghuli, A., Kazmerski, L. (2012). A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results.

Shanhan, Z. (2012). China to have 3 GW of Concentrated Solar Thermal Power (CSP) by 2020.

Solarcellcentral.com. Solar efficiency limits.

thegenerator.com.au. (2014) EIA-Independent Statistics and Analysis http://thegenerator.com.au/u-s-energy-information-administration-eia-independent-statistics-and-analysis-2/

Thomas W. Overton, JD, Plant of the year: Ivanpah solar electric generation system earns power's highest honor. August, 2014. http://www.powermag.com/ivanpah-solar-electric-generating-system-earns-powers-highest-honor/

U.S. Geological Survey, EROS Data Center: GTOPO30 Digital Elevation Model (Data downloaded from EROS web site)

Wesoff, E. (2013). The sunset of Solel, Siemens and Solar Trough CSP Technology.

Wesoff. E. (2012) Can solar CSP be integrated with a fossil fuel plant? http://www.greentechmedia.com/articles/read/can-solar-csp-be-integrated-with-a-fossil-fuel-plant

Wiesenberg, R., Hernadez, C., Serrano, E. Market outlook for CSP projects in China.

Wu, Z., Hou, A., Chang, C. (2014). Environmental impacts of large-scale CSP plants in northwestern China.

Xinhua. (2014). http://news.xinhuanet.com/2014-12/15/c_1113646848.htm